Appendix A

REPORT ON THE FINITE ELEMENT ANALYSIS OF 30 in. BUBBLE CHAMBER COIL

Submitted to

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Batavia, ILL.

April 27, 1981

INTRODUCTION

The purpose of this report is to explain the finite element analysis performed on 30 in. Bubble Chamber Coil. Computed stress values at critical sections of the coil are presented together with those requested by Mr. Craddock in his letter of April 13, 1981.

Bubble Chamber Coil is basically a circular ring having a rectangular box cross-section. The objective of this finite element analysis is to determine "overall" stress distribution under three load cases supplied by Fermilab. No attempt is made to determine stress concentrations. General purpose finite element program ANSYS is utilized to perform the analysis.

A brief description of the finite element model for the Bubble Chamber Coil together with the analysis assumptions are presented in the first part of this report. Second part contains the definition of the loads used in each of the three load cases considered and a summary of stresses at critical sections. Discussion of results and recommendations are presented in the conclusions.

FINITE ELEMENT MODEL

Quarter symmetry is assumed for the deformed structure under the three load cases considered. Consequently, one-quarter of the Bubble Chamber Coil is modeled for the finite element analysis. Appropriate boundary conditions are specified at the end sections of the model in order to preserve the symmetric behavior.

One layer of ANSYS STIF 45 elements are utilized in the model of coil cross-section. STIF 45 element is an eight noded brick with added extra displacement shapes in order to improve the bending effectiveness. ANSYS STIF 63 plate elements are used in modeling gusset plates and the plate sections at the top of the gussets. ANSYS STIF 9 pipe element is utilized for representing supports shown in details B and C of Fermilab drawing #2771-ME-56355 sheet #2.

The following simplifications are made in the model:

1. Screw and helium holes are not modeled. Since they don't affect "overall" stress distribution.
2. Support shown in the Fermilab drawing detail B is assumed to be located at zero degrees.
3. Gusset locations are assumed to be at thirty and sixty degrees relative to the model reference line.

Dimensions used in the model are obtained from the drawing given by Fermilab (Document 1, Appendix A). Element configuration on a coil cross-section and on a gusset is shown in Fig. 1. A detailed drawing of plate elements representing gusset and their numbers are given in Fig. 2. A three dimensional plot of the model showing finite elements is attached to this report. Six STIF 45 elements are used at each wall of the coil (Fig. 1) in order to determine bending and hoop stresses in an "overall" sense. For checking the accuracy of these elements, a cantilever beam subjected to a concentrated load at its tip is modeled by three STIF 45 element The results obtained for this model are found to be accurate and they are presented in Appendix B.

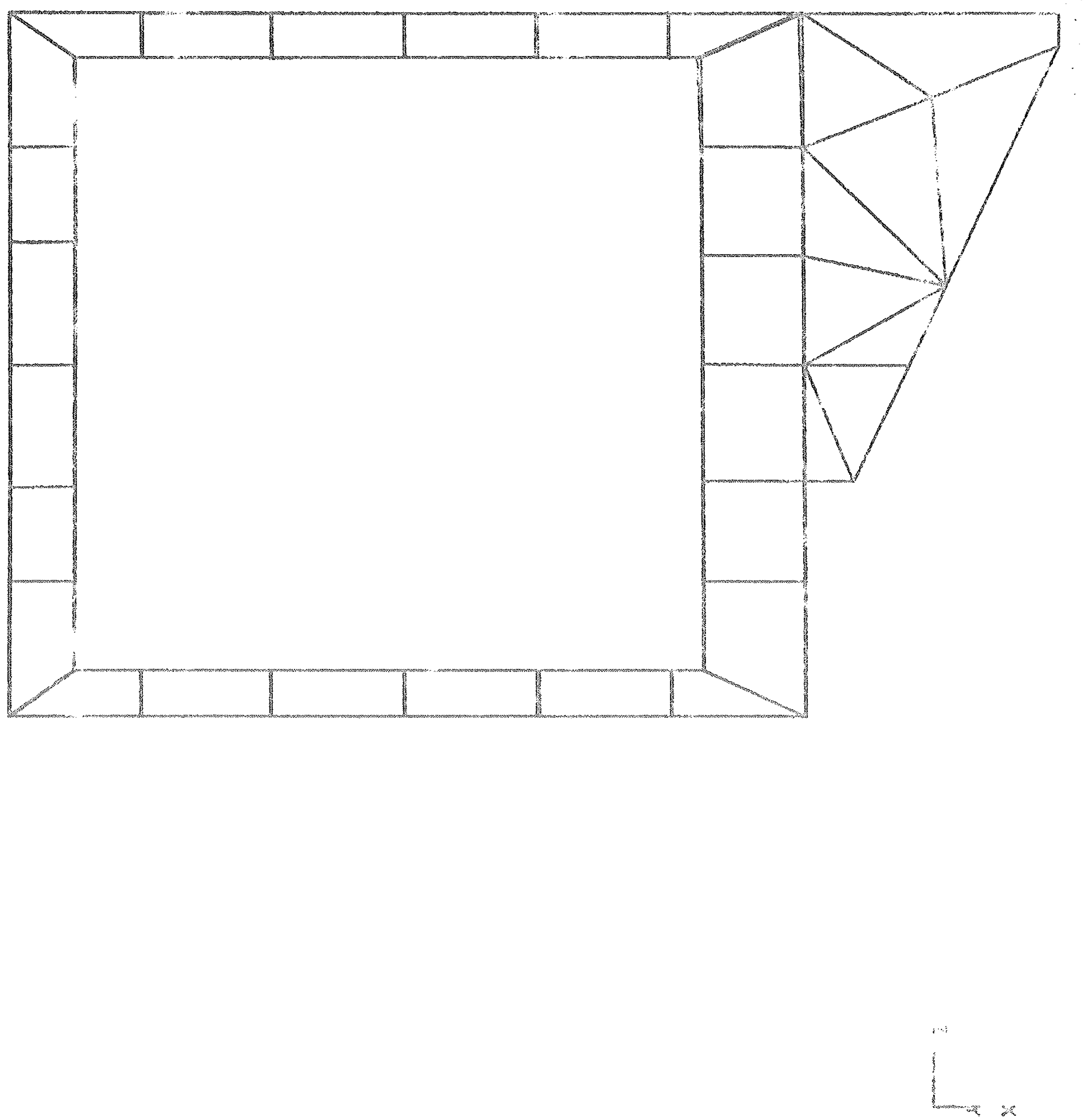


Figure 1. Element Configuration on coil cross-section and at gusset plate

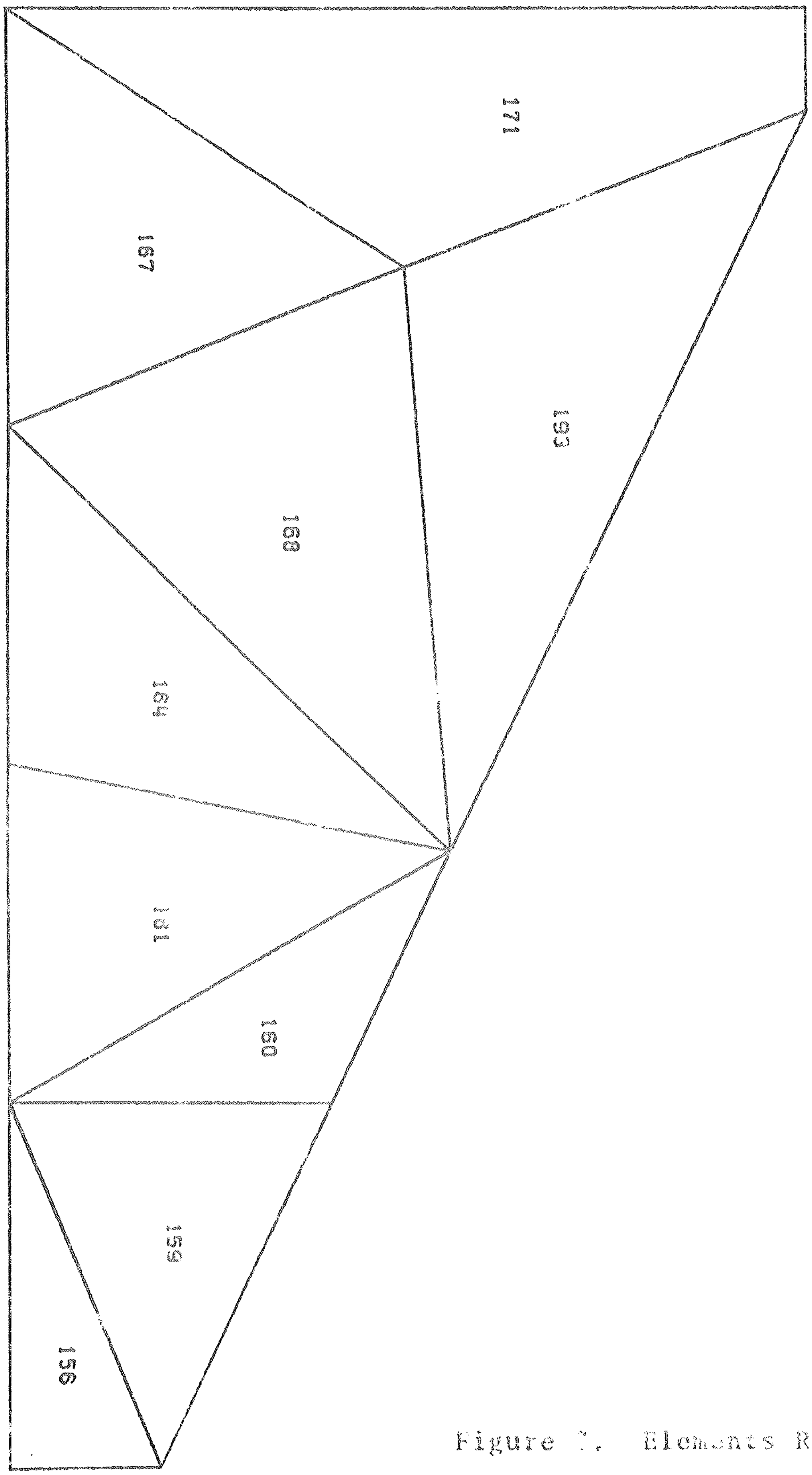


Figure 7. Elements Representing Gusset Plate

ANALYSIS ASSUMPTIONS

In addition to the modeling simplifications presented in the previous section, the following assumptions are made in the analysis:

1. Material is homogeneous and isotropic.
2. Material is linear elastic having modulus elasticity, E = 29900 ksi, and Poisson's ratio $\nu = 0.3$.
3. Deflections are small thus small deflection theory is applicable.
4. Local and overall buckling is not considered.
5. Residual stresses as well as stress concentrations are not considered.

LOAD CASES

Finite element analysis for the coil is performed for three load cases. Loads considered in these cases are those given in items 1, 2 and 4a of Mr. Craddock's letter of March 10, 198[illegible].

Load Case 1

An axisymmetric radially outward force of 9900 lbs. at each bolt location on the outer cylinder is considered in Load Case 1. Thus, three 9900 lbs. concentrated radial nodal forces are applied at six degree intervals. At the end sections (zero and ninety degree sections) 4950 lbs. concentrated nodal forces are taken to preserve the symmetry.

Load Case 2

An axisymmetric radially outward force of 7100 lbs. at each bolt location on the inner cylinder is considered in Load Case 2. Thus three 7100 lbs. concentrated radial nodal forces are applied at six degree intervals. At the end sections (zero and ninety degree sections), 3550 lbs. concentrated radial nodal forces are taken to preserve the symmetry. It should be noted that the loads considered in load cases 1 and 2 are acting along the same radial lines.

Load Case 3 Same as Load Case 4A from other Documents

Axisymmetric pressure acting on the top and bottom annular [illegible] is considered in this load case. Pressure distribution [illegible] Fermilab (Document II, Appendix A) is utilized. First segment of the pressure is applied to the top annular plate. Second segment is considered for the bottom annular plate. Constant pressures approximated from the pressure diagram are determined for each finite element surface subjected to pressure loading. Thus, variation of pressure values are considered by specifying different constant pressure for each element.

SUMMARY OF COMPUTED STRESSES

An overview of stress distributions are presented in this section. For a specific stress value computer output must be referred. For load cases 1 and 2, the stresses remain approximately the same at all radial sections of the coil. Consequently stresses at a typical cross-section through a helium hole location between two gussets are presented. Figures 3 through 8 show the hoop and bending stresses at the outer surface of the typical cross section together with the finite element numbers for load cases 1 through 3. For Load Case 3 stress distribution at radial section through gussets is different than those at the other sections due to the reactions at the gusset areas. Figs. 9 and 10 illustrate the stress distributions at the gusset section for load case 3.

For load case 3, the maximum principal stress is found at element 193 (see Fig. 2) in the gusset as $\sigma_1 = 26000$ psi. The other principal stress is $\sigma_2 = -3780$ psi. It should be noted that the stresses at gussets are much lower in load cases 1 and 2. Maximum Von Mises stresses are presented in Table I.

Table I. Maximum Von Mises Stresses

Load Case No.	Max. Von Mises Stress psi	Location in the Model
1	16,700	Element #62 At the junction of outer cylinder and detail 3 at 9.6 degree section
2	23,500	Element #47 At inner cylinder between 6 and 9.6 degree sections
3	28,000	Element #193 on gusset
	23,500	Element #461 At bottom annular plate between 72 and 78 degree sections

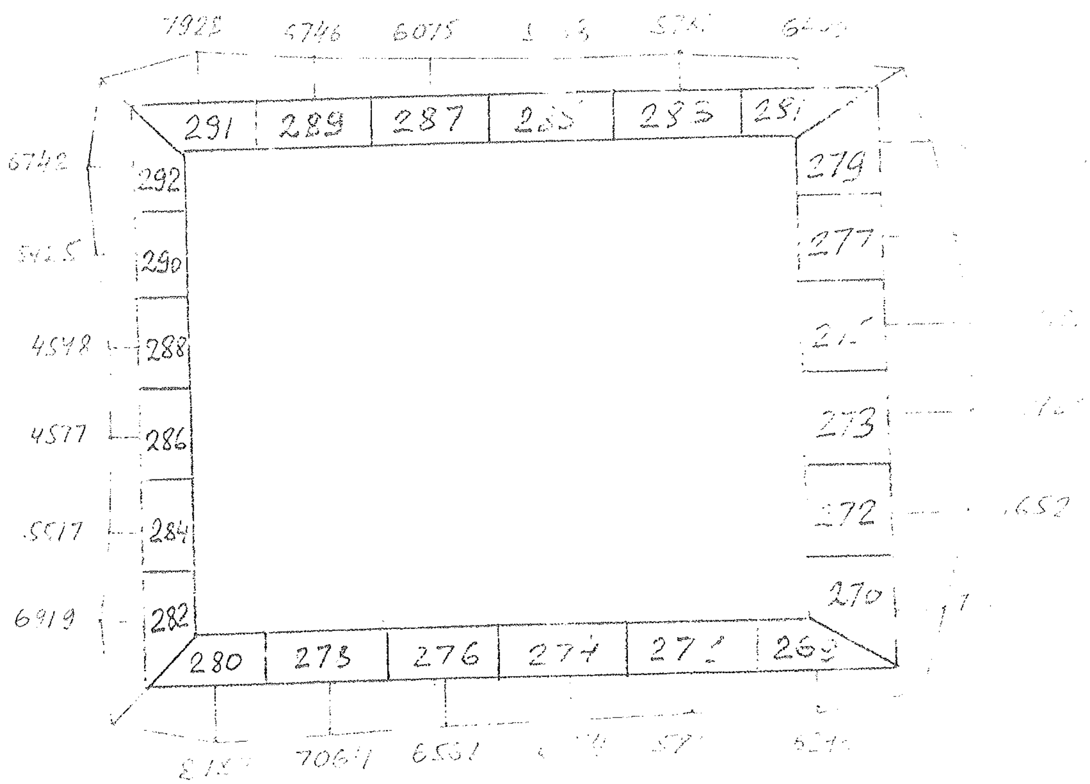


Figure 3. Outer Surface Hoop Stresses, Sx (psi), at a Typical Coil Section for Load Case 1.

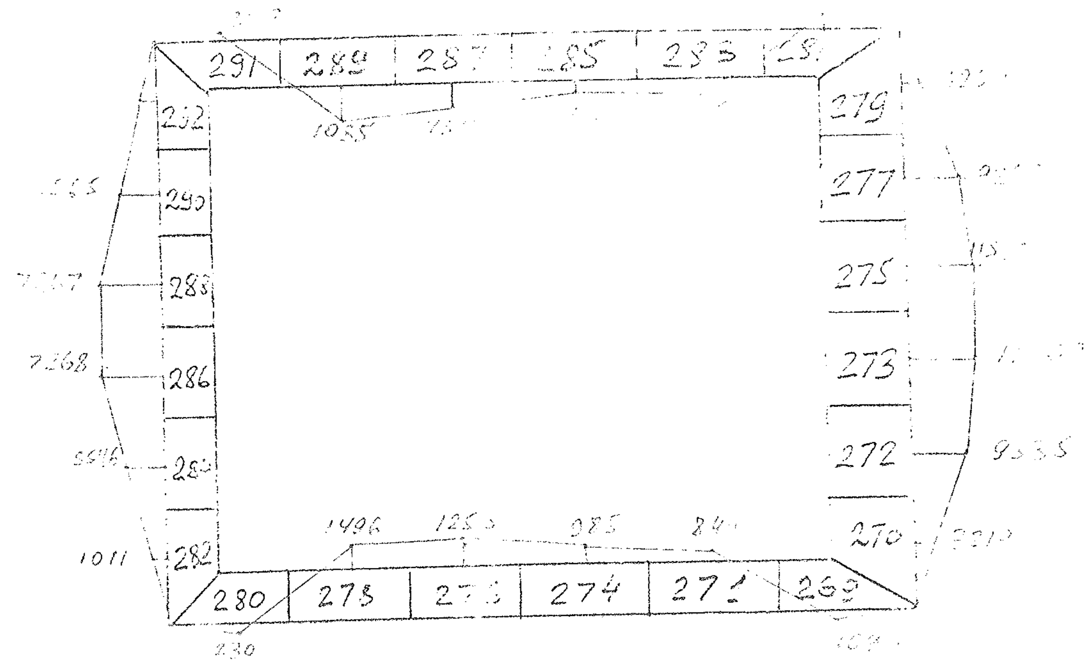


Figure 4. Outer Surface Bending Stresses, S... (psi), at a Typical Coil Section for Load Case 1

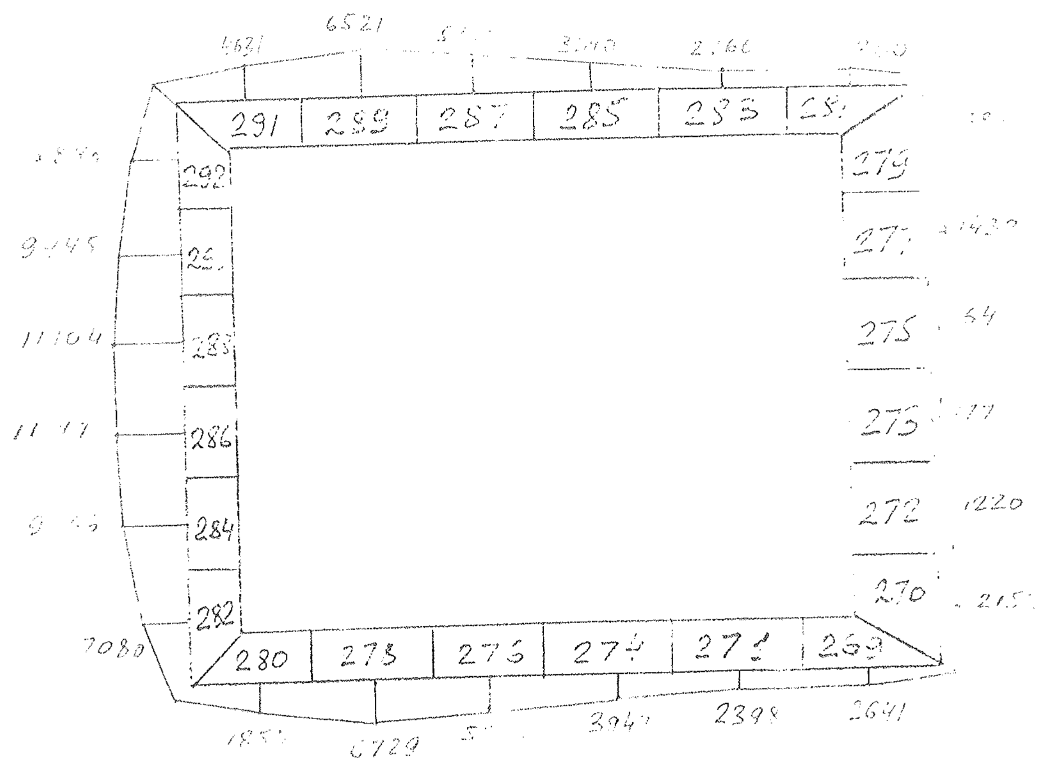


Figure 5. Outer Surface Hoop Stresses, S... (psi), at a Typical Coil Section for Load Case 2

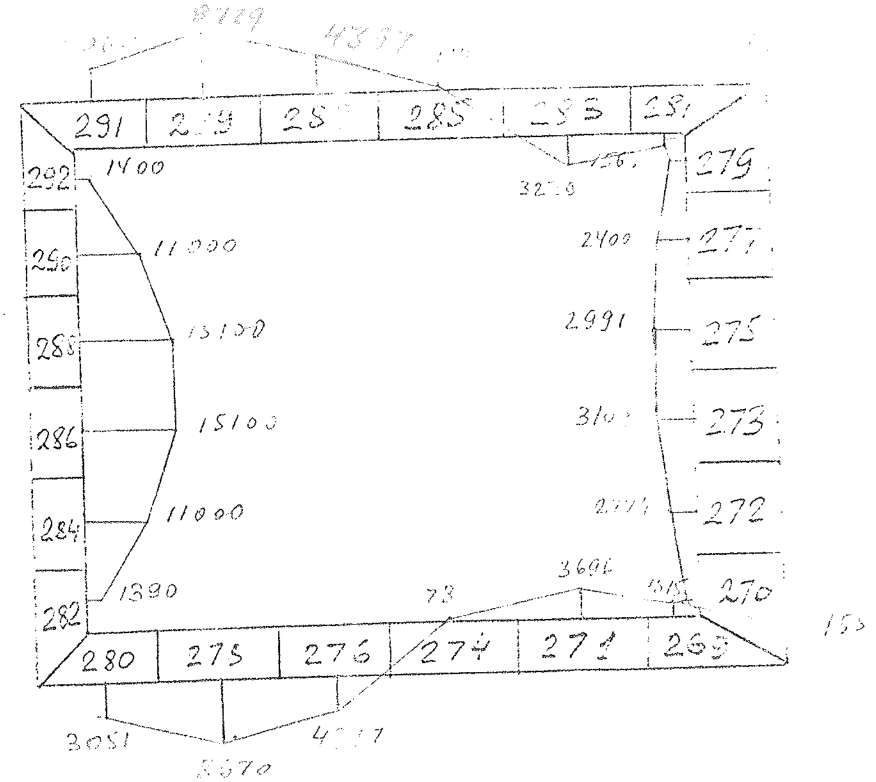


Figure 6. Outer Surface Bending Stresses, S_y (psi), at a Typical Coil Section for Load Case 2

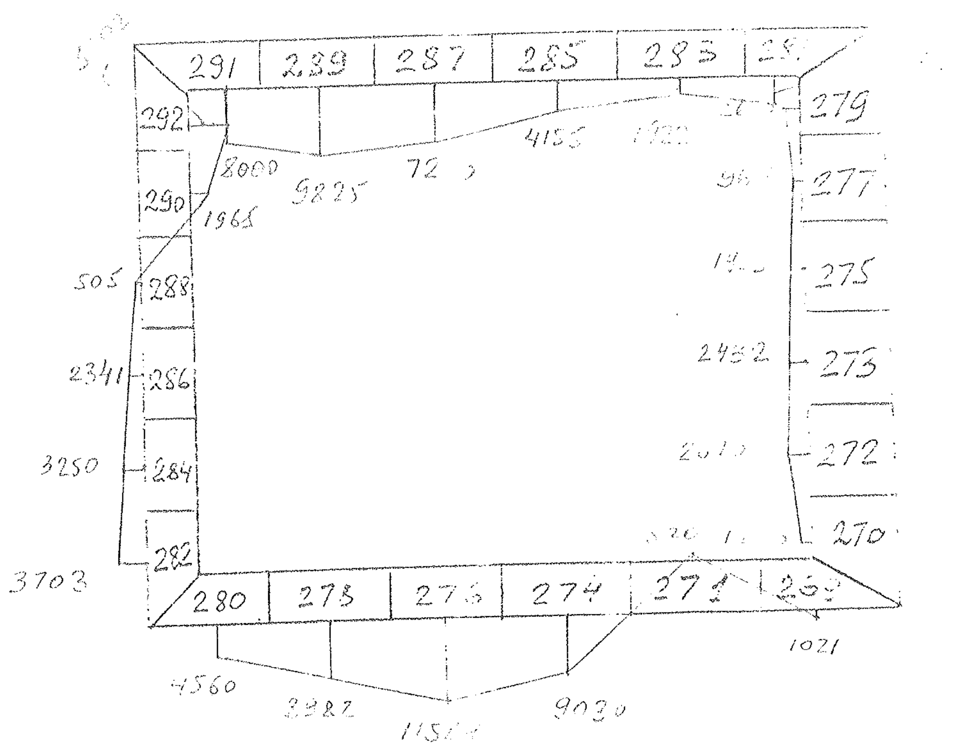


Figure 7. Outer Surface Hoop Stresses, S (psi) at a Typical Coil Section fo ad Case 3

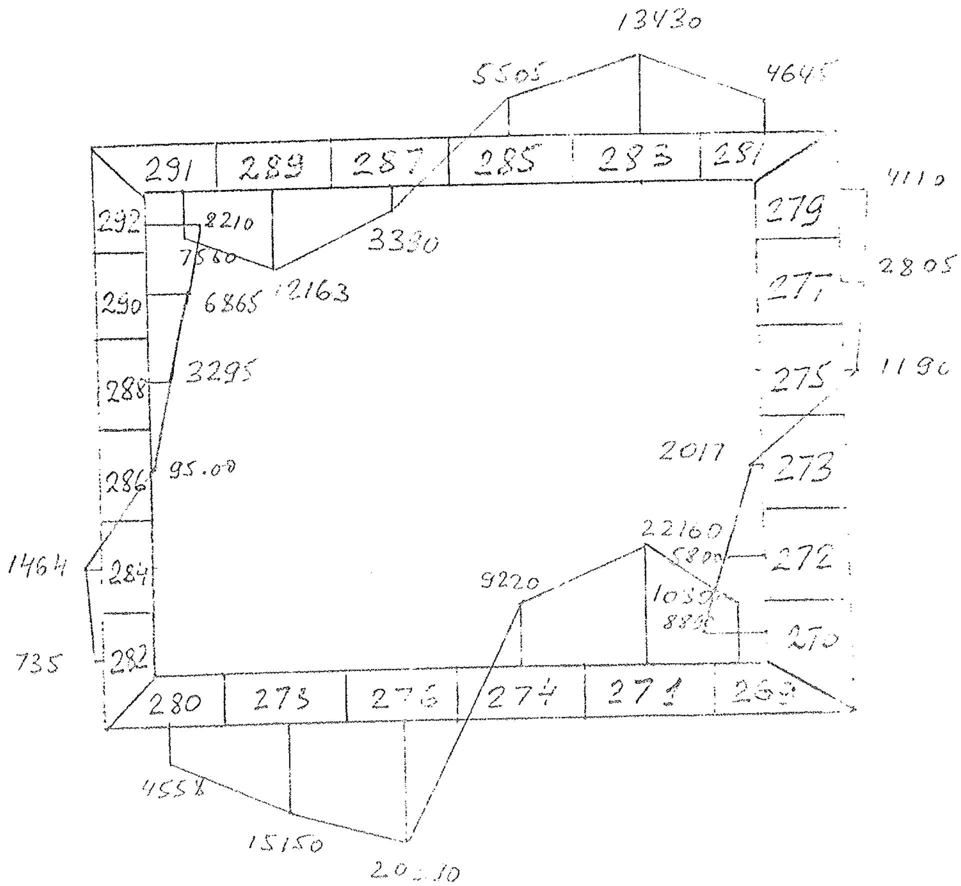


Figure 8. Outer Surface Bending Stresses, S_y (psi), at a Typical Coil Section for Load Case 3

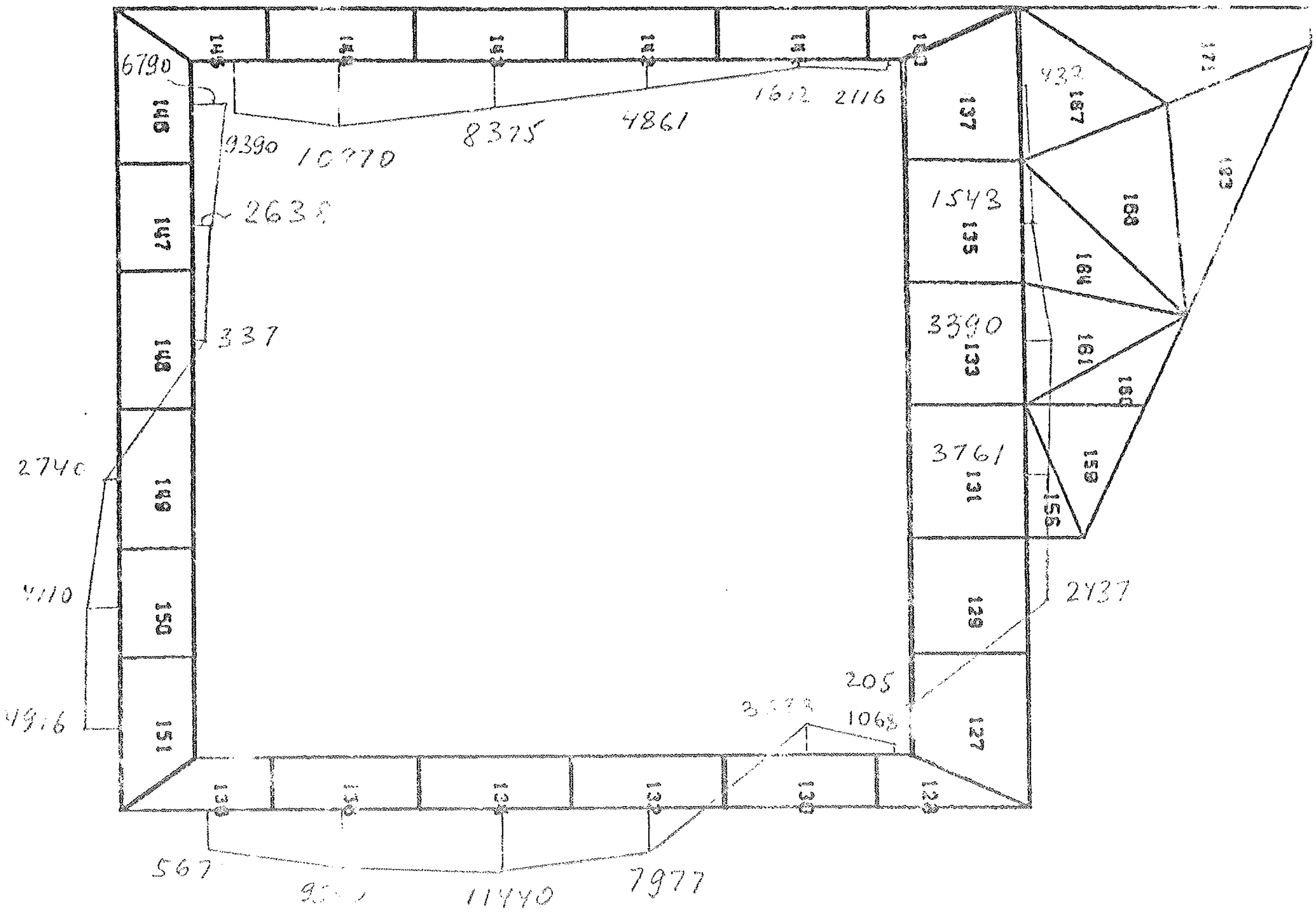


Figure 9. Outer Surface Hoop Stresses, S_x (psi), at a Typical Coil Section through Gusset for Load Case 3

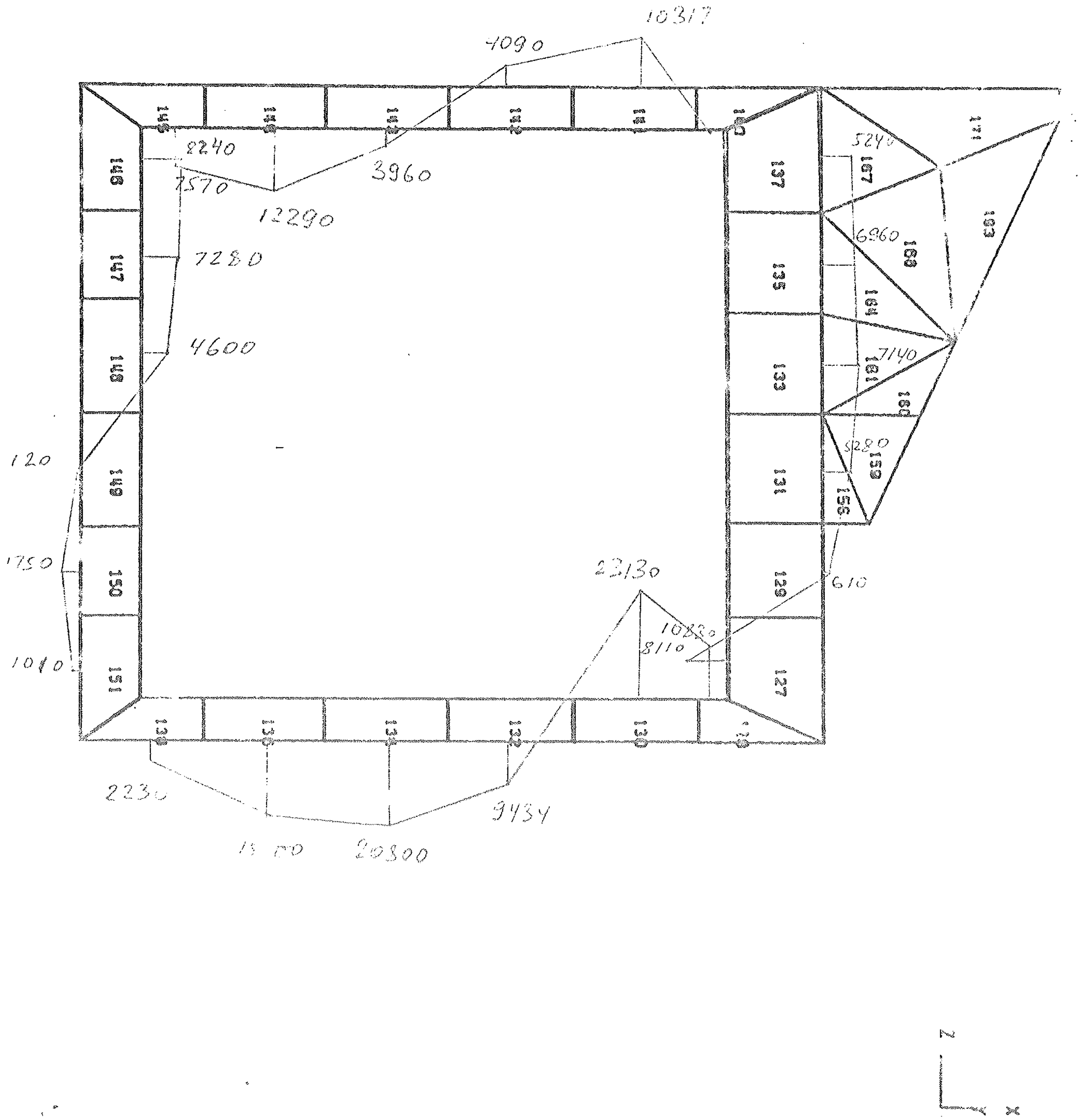
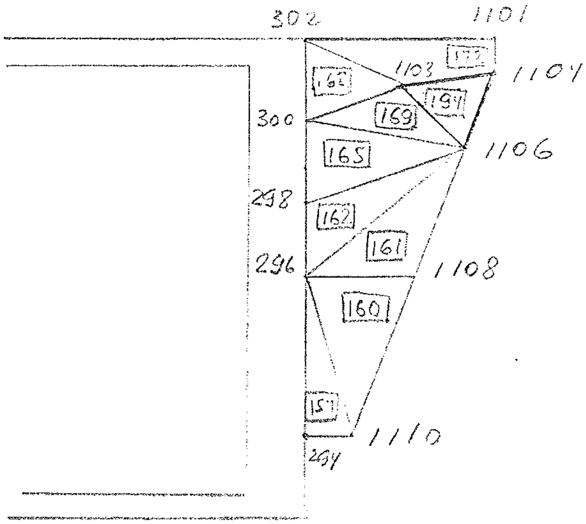


Figure 10. Outer Surface Bending Stresses, S_y (psi), at a Typical Coil Section through Gusset for Load Case 3

Case #4a is the axial load case

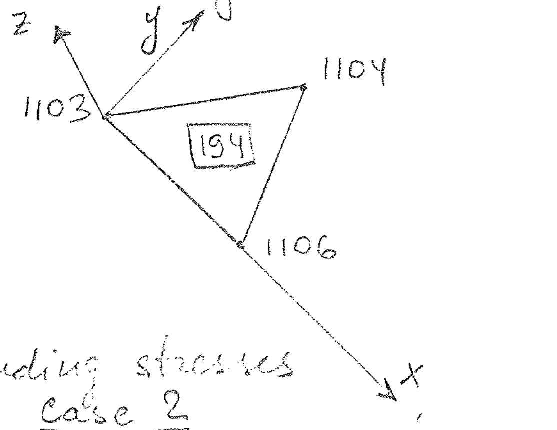
Detail A



Case 4a

[194] - Element number

The highest stressed el-t is 194



Combined membrane & bending stresses

Case 1

$\sigma_x = 2725$ $\sigma_1 = 2725$
$\sigma_y = -950$ $\sigma_2 = -955$
$\tau_{xy} = -100$ $\tau_{max} = 1840$

Case 2

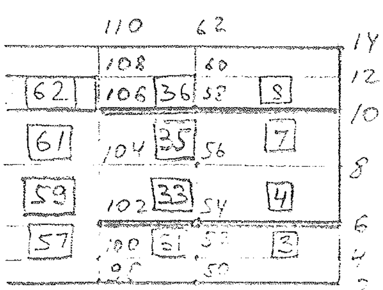
$\sigma_x = -1328$ $\sigma_1 = 165$
$\sigma_y = 130$ $\sigma_2 = 1370$
$\tau_{xy} = -240$ $\tau_{max} = 765$

Case 4a

$\sigma_x = 17000$ $\sigma_1 = 25120$
$\sigma_y = 4200$ $\sigma_2 = -3870$
$\tau_{xy} = 13000$ $\tau_{max} = 14500$

Detail B

$x = r$
$y = z$ down
$\sigma_x = \theta$



The highest stressed el-t is 62

Case 1 $\tau_{max} = 5220$

$\sigma_x = -89.9$ $\sigma_1 = 10160$
$\sigma_y = 9590$ $\sigma_2 = -142$
$\sigma_z = 346$ $\sigma_3 = -276$

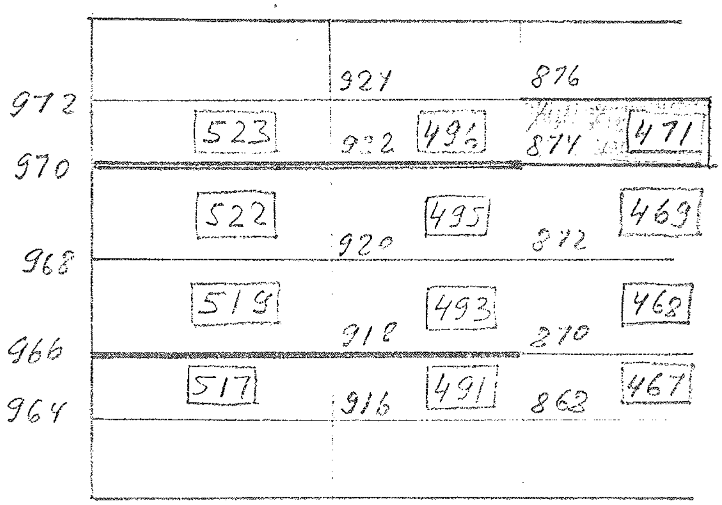
Case 2

$\sigma_x = 265$ $\sigma_1 = 3841$ $\tau_m = 1970$
$\sigma_y = 3625$ $\sigma_2 = 467$
$\sigma_z = 320$ $\sigma_3 = -102$

Case 4a

$\sigma_x = -190$ $\sigma_1 = 630$ $\tau_{max} = 2335$
$\sigma_y = -3840$ $\sigma_2 = -75$
$\sigma_z = 582$ $\sigma_3 = -4035$

Detail C



$x = r$
$y = z$ down
$x = \theta$

The highest stressed elt is 471

<u>Case 1</u>

$\sigma_x = 8460$ $\quad \sigma_1 = 9626$ $\quad \tau_m = 5075$

$\sigma_y = 470$ $\quad \sigma_2 = 257$

$\sigma_z = 428$ $\quad \sigma_3 = -522$

<u>Case 2</u>

$\sigma_x = 3490$ $\quad \sigma_1 = 3880$ $\quad \tau_m = 2026$

$\sigma_y = 424$ $\quad \sigma_2 = 481$

$\sigma_z = 250$ $\quad \sigma_3 = -171$

<u>Case 4a</u>

$\sigma_x = -2$[illegible] $\quad \sigma_1 = 1030$ $\quad \tau_{max} = 2325$

$\sigma_y = -85$ $\quad \sigma_2 = 100$

$\sigma_z = 215$ $\quad \sigma_3 = -3625$

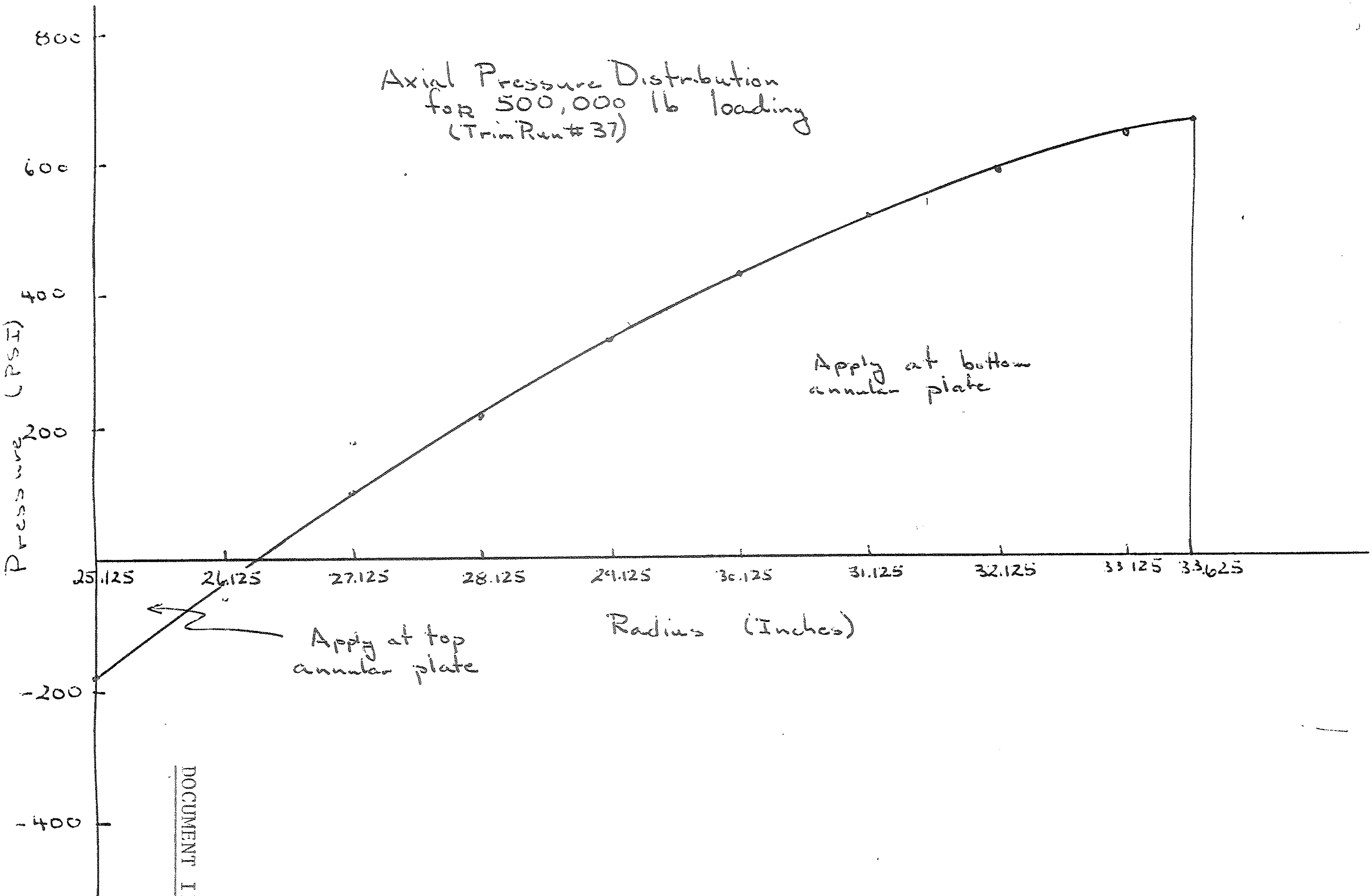
SUMMARY AND CONCLUSIONS

A quarter-symmetric finite element model for 30 in Bubble Chamber Coil is developed. Finite element analysis is performed on the model for three load cases. The objective of the analysis is to determine "overall" stress distribution for each load case. Screw and helium holes are not included in the model. Accurate local stress distributions at the corners of the coil section as well as around the holes, can be obtained by using refined models for these areas. Consequently, the stress values presented in this report approximate the overall stress distribution.

APPENDIX A

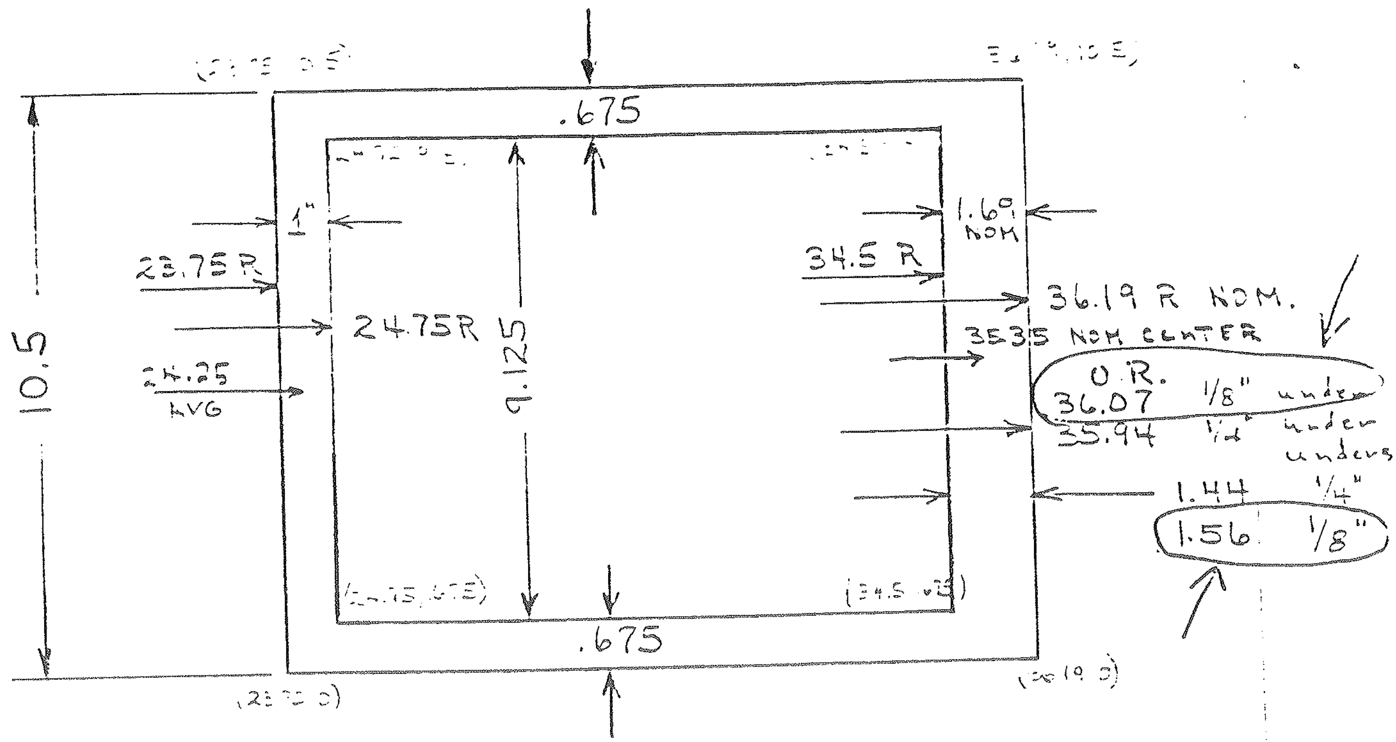
DOCUMENTS

Figure 1



DOCUMENT II

Cryostat Parameters



Outer wall under by 1/8" → 1.3" sq in" loss of materi

1/4 → 2.6 sq in loss

DOCUMENT I